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Research on Detection of Heated Pipelines Underground by Infrared Imaging

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Abstract: The oil in the pipelines must be heated to a certain temperature in some oil fields in north of China. Otherwise, the oil will freeze because of much paraffin mixed in it. A method to detect the direction of the pipeline underground accurately is described in the paper. The temperature of the pipelines can conduct to the surface of the soil and be detected by an uncooled focal plane arrays (UFPA) sensor. The output of the thermal infrared sensor can be expressed as the gray thermal pictures. According to the different degree of gray in the thermal pictures, the temperature distribution of the soil surface can be obtained, and then the direction of the pipelines underground can be judged. The advantage of the method is simple operation, direct display and harmless to human and the environment. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Pipeline, Non-destructive testing, Infrared imaging, Uncooled focal plane arrays.

1. Introduction

Because of being buried underground, the direction and the situation of a pipeline are difficult to be detected. There are several methods for the underground pipelines detection, such as radar reflection, electronic-magnetism, pressure wave, isotope, etc. The method of the radar reflection or the electronic-magnetism can judge the direction of the pipelines underground, but it can't detect the leakage. The method of the negative pressure wave can examine the quick leakage of the pipelines underground, but it isn't suitable for judging the direction of the pipelines [1, 2]. The method of the isotope can examine the pipelines and site the leakage, but it will pollute the environment in some degree. Therefore, each of these methods has its own advantage, but there is not a suitable method for the slow and long-term leakage [3-6].

2. Temperature Characteristics

2.1. Infrared Temperature Measurement

The pictures of the temperature distribution of the surface are taken by the infrared thermal imager. The device is composed by the infrared camera, the infrared sensor, the optical imaging system and the electronic processing system. The infrared radiation energy distribution of the object is reflected on the photosensitive element in the infrared sensor, and the sensor converts the infrared radiation energy into the electrical signals. The electrical signals are amplified and translated into standard video signals, and then the infrared pictures are shown on the monitor.

The infrared picture is corresponding to the temperature distribution on the surface of the soil, and it is the distribution picture of the infrared radiation temperature field of the pipeline

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underground. Due to the signal is very weak, compared with visible picture, the infrared picture is lack of administrative levels feeling and the stereo feeling. In order to judge the infrared thermal distribution of the measured object more effectively, some software processes as the auxiliary measures are used to enhance the image display, such as the image brightness and contrast control, the linear correction, the contour extraction, the threshold value segmentation, the pseudo color paint, etc.

Only the different wavelength range of noise equivalent temperature difference (NETD) values are calculated, the thermal imaging system can reflect the same relative performance of the two thermal imaging of the same aspects and the different band. In the case of background restrictions, the NETD value is shown in equation 1 [7, 8].

$$NETD=\frac{\pi\sqrt{ab\Delta f_R}}{\alpha\beta A_0\tau_0 D^*_{BLIP}(\lambda_P)}\bullet\frac{T_B^2\lambda_P}{C_2\int_{\lambda_1}^{\lambda_P}W_\lambda(T_B)d\lambda}, \quad (1)$$

where a, b is the size of each sensor; α, β is the field angle of each sensor; TB is the background temperature; $D^*_{BLIP}(\lambda_P)$ is the function of the detectivity and the band; A0 is the efficient collection area; τ0 is the transmission value of the optical system; ΔfR is the equivalent noise bandwidth of the standard filter; Wλ is the emission measure of the spectral radiance; C2 is a constant.

All objects above 0 K can emit thermal infrared energy. The fluid in a pipeline has a certain temperature and the temperature can conduct to the surface of the soil, so a thermal infrared sensor to measure the temperature of the soil surface can be used. The temperature of the soil above the pipeline is higher than which in other positions, so the direction of the pipeline underground can be judged by the difference of the temperature of the soil surface.

On the basis of the theory of the thermal infrared measurement, the method measures up to the criterion of the safety. The device can examine the infrared energy and display the pictures, which is capable of providing very detailed images of invisible situations. The infrared detection of the pipelines has already applied for many years, but it is mainly used in the field of electric power, such as the detection of the electrical wirings, the situation of the electrical devices, and so on. It is easy and quick to confirm the situation of the pipelines underground by using of the method, so we can deal with the trouble in time. The instrument is applied for the safety of the oil field. The most prominent advantage of the method is that it is harmless to human and the environment [9].

2.2. Temperature of Soil Surface

Much paraffin is mixed with the oil in most of the oil wells in China. The oil will freeze without be heated. So, the oil in the pipelines must be heated to a certain temperature (45~85 °C). According to the theory of thermal conduction, the temperature of a pipe underground can conduct to the surface of the soil. A theoretic thermal conduction curve of a pipe is shown in Fig. 1. The diameter of the pipe in the example is 76 cm.

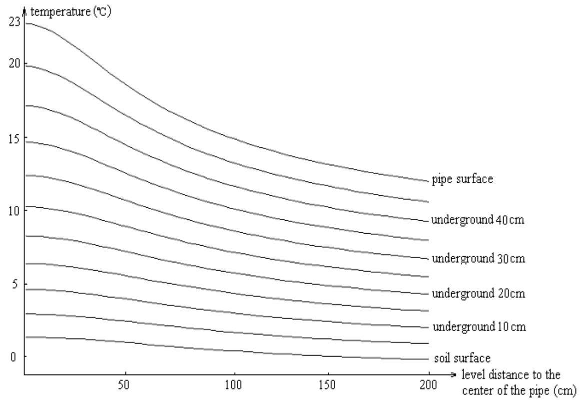


Fig. 1. Theoretic thermal conduction curve of a pipe underground.

The temperature in the oil pipe is common 50-70 °C, but the surface temperature of the pipe is lower for the insulating layer. Now there is a pipeline with the 50 mm diameter and 55 cm depth under the soil. The surface temperature is 44.5 °C. Some precise thermometers are placed on the soil surface, which is just above the pipe underground. The minimal scale of the thermometer is 0.1 °C. The distance between two thermometers is 10 cm. The method of the experiment is shown in Fig. 2.

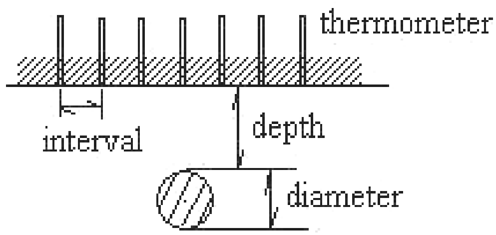


Fig. 2. Temperature measure of soil surface.

The temperature distribution parameters are measured for the surface, 10 cm underground and 20 cm underground of the pipe. The thermometers are vertical with the pipeline direction and located two sides of the pipeline center. The interval of two thermometers is 15 cm and the measure distance is 120 cm. To avoid the solar radiation, the measure time is chosen at 1:00-3:00 AM. The surface temperature of the soil without pipeline is constant 19.1°C.

As a result of the experiment, the temperature of the soil surface just above the pipe is very different from other places.

The maximal difference of the temperature between 10 cm of the soil surface is almost 1 °C. The temperature values of a certain experiment are shown in Table 1. The errors for the seasonal conversion in one year and the time variation in one day belong to the systemic error. Therefore, for a certain soil area, the temperature difference with 1 °C can be detected by the infrared sensor.

Table 1. Temperature distribution of pipeline underground.

Time 1:30 Surroundings' Temperature 18.5 ºC	Position	1	2	3	4	5	6	7	8	9
	Surface	20.3	20.3	20.4	20.7	21.7	21.8	20.7	21.0	20.2
	Underground 10 cm	22.5	22.7	23.4	24.3	25.0	24.6	24.3	23.6	23.5
	Underground 20 cm	24.3	24.5	25.7	26.7	27.4	27.5	26.8	26.3	25.7
Time 2:00 Surroundings' Temperature 18.2 ºC	position	1	2	3	4	5	6	7	8	9
	Surface	19.6	20.1	20.0	20.5	21.6	21.7	20.4	20.4	19.8
	Underground 10 cm	22.4	23.2	23.2	24.0	24.8	24.3	24.0	23.4	23.3
	Underground 20 cm	24.2	24.6	25.7	26.7	27.5	27.4	26.7	26.2	25.7
Time 2:30 Surroundings' Temperature 18.0 ºC	position	1	2	3	4	5	6	7	8	9
	surface	19.9	20.0	20.1	20.5	21.5	21.7	20.4	20.3	19.9
	Underground 10 cm	22.3	22.6	23.0	23.9	24.7	24.3	23.9	23.4	23.2
	Underground 20 cm	24.0	24.6	25.5	26.7	27.5	27.4	26.7	26.0	25.8

The data are approximately same after many reduplicate experiments. Therefore, the aim of the instrument is to measure the difference of the temperature accurately. In terms of the data in lots of experiments, there is a difference about 1 °C in the surface of the soil between 10 cm intervals for a pipeline whose diameter is 76 mm, temperature is 50 °C and depth is 50 cm underground. The typical signal response of UFPA is 7 mV/K. Then, it is enough to measure the difference.

3. Characteristic of Sensor

The sensor is the infrared focal plane array and the number of the pixels is 320 × 240. Infrared imaging sensors that operate without cryogenic cooling have the potential to provide the military or civilian users with infrared vision capabilities packaged in a camera of extremely small size, weight and power. Uncooled infrared sensor technology has advanced rapidly in the past few years. Higher performance sensors, electronics integration at the sensor, and new concepts for signal processing are generating advanced infrared focal plane arrays. This would significantly reduce the cost and accelerate the implementation of sensors for applications such as surveillance or predictive maintenance. The precision of the uncooled sensor is lower than that of the cooled one, but the response time is shorter. To show the thermal pictures in real time, the uncooled detector is suitable for the application [10].

Compared with cryogenic cooled devices, room temperature uncooled infrared bolometric sensors offer considerable advantages in cost and operational convenience with minimal sacrifice in performance. Advantages of uncooled bolometers include higher reliability, reduced power consumption, smaller size and reduced weight, as well as multispectral response capability.

Uncooled technology is revolutionizing infrared (IR) detection and imaging providing low cost, reliable sensors for civilian and military applications. Compared with cryogenic cooled devices, room temperature uncooled IR bolometric detectors offer considerable advantages in cost and operational convenience with minimal sacrifice in performance. Advantages of uncooled bolometers include higher reliability, reduced power consumption, smaller size and reduced weight, as well as multispectral response capability. For example, a kind of uncooled detector standard product that made in French, ULIS01011, is shown in Fig. 3.

Fig. 3. Shape of the detector.

Uncooled infrared detectors are now available for various applications. Their simple operating conditions are similar to those of CMOS Active Pixel Sensor (APS) or CCD digital camera. The pixels of the sensor are shown in Fig. 4. They have already shown their potentiality to fulfill many commercial and military applications. Nevertheless, as they are not cooled, no cold shield could be added to determine with precision the IR irradiance level.

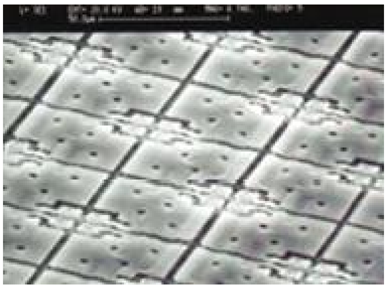


Fig. 4. Pixels of infrared sensor.

Consequently, they are very sensitive to temperature environmental conditions and optics and camera manufacturers have to take this behavior into account to address thermography applications by adding an internal temperature shield between the sensor and the lens.

4. Structure of System

The hardware of the instrument is consisted in several parts: the infrared camera lens, the sensor, the amplifier circuit, the A/D transition circuit, the portable computer and the power, and so on. The structure of the system is shown in Fig. 5.

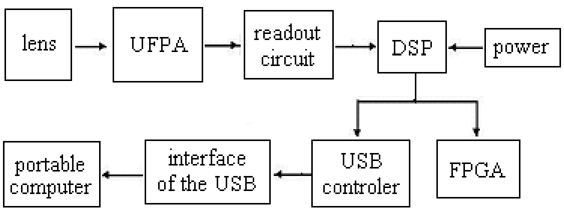


Fig. 5. Structure of system hardware.

The flow of signals is shown as followed. The infrared camera lens is made up of the Germanium, a special metal for infrared detection, and collects the difference of the temperature of the soil surface. The optical signals are transformed into electronic signals by the sensor circuit. The sensor is suitable for the observation in particular in the long waveband of the infrared (8~14 μm). Having been amplified by the amplifier circuit, the signals will change from analogue to digital by passing the A/D transition circuit. Then, the data of the thermal pictures is obtained. The data is processed by the CPU of the portable computer and is shown in the screen by the meaning of the pictures [11]. The pictures on the screen are the reflections of the pipelines underground.

The picture data are large and the processing needs very quick speed, so the portable computer is adopted. The function of the computer is stronger than that of DSP (digital signal processor), so the real-time detection can be finished satisfactorily [12].

5. Results of Experiments

5.1. Lens View Place

The horizontal field angle of the infrared lens is θ, and the vertical measure height is h. If the lens is directly facing the soil, then the horizontal field range is shown in formula 2.

$$L = 2 \times h \times tg(\theta / 2) \qquad (2)$$

For the common infrared lens, the horizontal field can not cover all of the objects. If the horizontal fields are needed to extend, then the lens must be inclined. If the horizontal field range is required to be L, then the inclined angle is shown in formula 3.

$$\alpha = 2 \times (arctg(L/2/h) - \theta) \qquad (3)$$

The height of the hand-held thermal imager is 1.5 m. In view of the radiation energy missing for the shine obliquely, the inclined angle is 45°. This is the principle of the picture collection.

The thermal imaging and the picture identification are the pivotal technologies in the research. To get more information from the pictures, the precision of UFPA must be improved. To identify the direction of pipes more accurately, the mathematic algorithm is used. For example, real-time imitative color and gray proportion can make the object clearer and easier to be identified, and liminal value can be controlled for workers to distinguish the principle part from the background. The pictures of the same object are dissimilar if the algorithm values are different. There are a few examples that shown as followed.

5.2. Results of Pictures

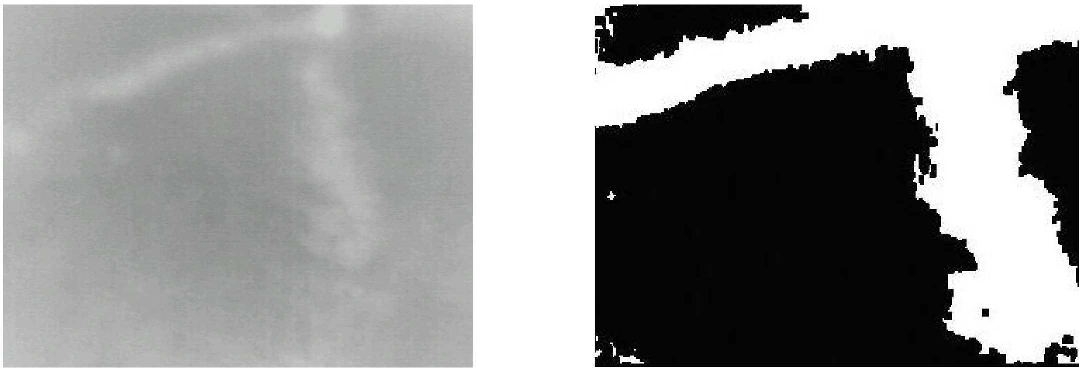
The thermal imaging and the picture identification are the pivotal technologies in the research. To get more information from the pictures, the precision of UFPA must be improved. To identify the direction of pipes more accurately, the mathematic algorithm is used. For example, real-time imitative color and gray proportion can make the object clearer and easier to be identified, and liminal value can be controlled for workers to distinguish the principle part from the background. The pictures of the same object are dissimilar if the algorithm values are different. There are a few examples that shown as followed.

The picture of two cross pipelines is shown in Fig. 6. The diameter of each pipe is 30 mm, and the depth underground is 25 cm, and the temperature is 50 °C.

The picture (a) is the original picture that got from the UFPA and the readout circuit. The picture (b) is the result that processed after the algorithm.

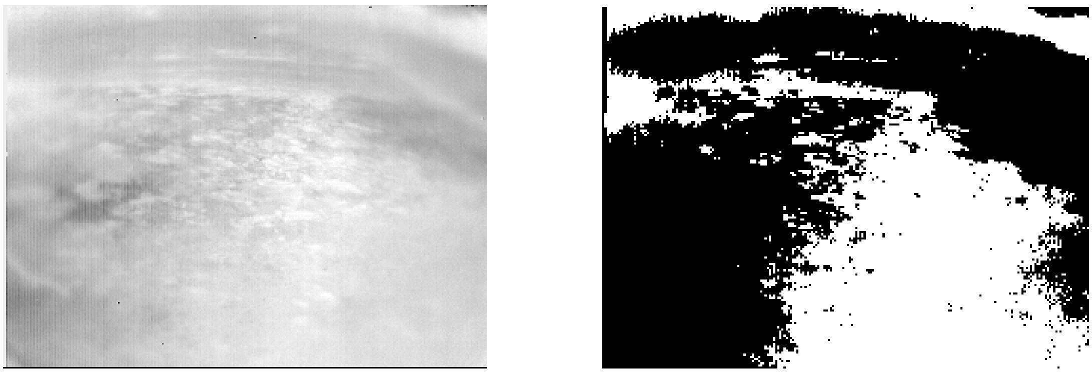
In the same way, the picture of a flexural pipeline is shown in Fig. 7. The diameter of the pipeline is 89 mm, and the depth underground is 35 cm, and the temperature is 30 °C.

The picture of a thick pipeline is shown in Fig. 8. The diameter of the pipeline is 325 mm, and the depth underground is 80 cm, and the temperature is 45 °C.



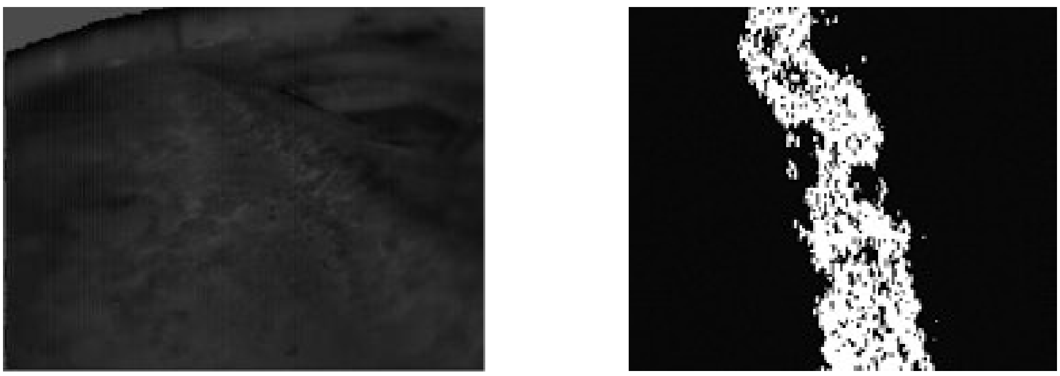
(a) (b)

Fig. 6. Two cross pipelines.



(a) (b)

Fig. 7. A flexural pipeline.



(a) (b)

Fig. 8. A thick pipeline.

All the experiments are not done in the sunshine. To detect the pipelines underground by this method in dawn is the best choice. Compare the picture (a) with (b), we can find the direction of the pipeline underground more clearly.

6. Conclusions

Besides be used in electronic power and biomedicine, UFPA can be used as an infrared sensor in other fields. An available method for the detection of the heated pipelines underground by using of UFPA is presented. It provides a useful tool to detect the directions and the situations of the pipelines underground. Affected by the environmental factors, the method has its limitation. It is not suitable for the place where the pipelines were buried too deep to be detected. In addition, the grass, the sunlight and the humidity of the soil are the factors that we must think about. To make some progress, the precision of the UFPA should be improved and the picture data process should be perfected.

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